The Role of Energy Storages in Energy Independent Croatia

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ULOGA SKLADIŠTENJA ENERGIJE U ENERGETSKI NEOVISNOJ HRVATSKOJ

U radu je analizirana integracija električne energije iz vjetroelektrana u energetski sustav Republike Hrvatske uz pomoć dostupnih tehnologija. Bazna godina za razmatranje modela hrvatskog energetskog sustava je 2007. Provedena je opsežna satna analiza cjelovitog hrvatskog energetskog sustava uz zadovoljavanje potrošnje električne energije, daljinske topline i goriva u sektoru transporta te uključujući obnovljive izvore energije, termoelektrane i kogeneracijska postrojenja. Koristeći se modelom energetskog sustava iz 2007. povećan je udio električne energije iz vjetroelektrana primjenom dvije metode skladištenja energije: reverzibilne/crpne hidroelektrane te dizalice topline u kombinaciji sa skladištenjem toplinske energije. Rezultatima je prikazano da obje opcije omogućavaju povećanje penetracije energije iz vjetroelektrana. Koristeći postojeće reverzibilne/crpne hidroelektrane moguće je ostvariti povećanje penetracije energije iz vjetroelektrana od 0,5 TWh, no za veće penetracije od 6 TWh, potrebno je ipak izgraditi nova revirzibilna/crpna postrojenja. Koristeći velike dizalice topline s velikim akumulatorima topline u kombinaciji s posebnom regulacijom elektroenergetskog sustava moguće je dodatno povećati penetraciju za 0,37 TWh. Vezano uz to, oko 10% električne energije iz vjetroelektrana, može biti prihvaćeno bez promjena u sustavu te bez izvoza električne energije u elektroenergetske sustave susjednih zemalja. Za veće udjele energije vjetra potrebne su tehnologije za integraciju te posebno vođenje sustava. Za dobivanje što točnijih rezultata u budućim analizama potrebno je verificirati podatke o brzinama vjetra te proizvodnji vjetroelektrana i hidroelektrana. Nove tehnologije moraju biti primijenjene u ostalim dijelovima hrvatskog energetskog sustava ukoliko se želi postići vrlo velika integraciju električne energije iz vjetroelektrana.

THE ROLE OF ENERGY STORAGES IN ENERGY INDEPENDENT CROATIA

In this paper integration of wind power generation into the Croatian electricity supply is analysed using available technologies. The starting point is a model of the energy system in Croatia in 2007. Comprehensive hour-by-hour energy system analyses are conducted of a complete system meeting electricity, heat and transport demands, and including renewable energy, power plants, and combined heat and power production (CHP) for district heating. Using the 2007 energy system the wind power share is increased by two energy storage options: Pumped Hydro and Heat Pumps in combination with Heat Storages. The results show that such options can enable an increased penetration of wind power. Using pumped hydro storage (PHS) may increase wind power penetration from 0.5 TWh, for existing PHS installations and up to 6 TWh for very large installations. Using large heat pumps and heat storages in combination with specific regulation of power system could additionally increase wind penetration for 0.37 TWh. Hence, with the current

technologies installed in the Croatian energy system the installed pumped hydro-plant may facilitate more than 10% wind power in the electricity system. In future research more precise assessments can be made of whether to increase the storage size or whether to expand capacities in turbines and pumps. Using heat pumps also shows good the results in combination with CHP, in this paper and future research can give more precise results about such possibilities. With more wind, power integration technologies and system regulation are required. Additional confirmation of wind power data and hydropower production in Croatia is required to have more accurate results in future analyses. Large-scale integration of wind power in the Croatian energy systems requires new technologies in other parts of the energy system.

INTRODUCTION

The primary energy import dependence of European Union is currently around 53%, and it is expected that in the next 20-30 years it will reach or surpass 70% if no measures to prevent this are made. The situation in Croatia is similar. In 2007 the import dependence was 53.1% while for 2030 it is predicted to reach 72%. Such import dependence leads to decreased security of energy supply, due to current geopolitical situation in which main sources of fossil fuels are in unstable regions and in which the competition for those resources from developing countries is growing. The EU energy strategy, and a comparable Croatian strategy, is focused on policies and measures that will bring increase of share of renewable and distributed energy sources, increase in energy efficiency and energy savings and decrease in green house gas emissions.

The results of previous research has shown that in order to increase efficiency and viability, there is need for energy storage, in the primary or secondary form, in order to transfer energy surplus form period of excess to the period when there is a lack. The problem of storage systems is that they increase the cost of already expensive distributed and renewable energy sources, making them, in market circumstances, even less economically viable. Although there are a number of storage technologies, as chemical, potential or heat energy, not all those technologies are optimal for each energy system. Several authors have shown that by integration of energy and resource flows it is possible to decrease costs and that by rational energy managing and financial support that takes into account externalities, it is possible to devise such a system to be environmentally, economically and socially acceptable [1]-[18].

As the import of fuel to Croatia is increasing one of the measures to increase the security of supply is to increase the share of renewable energy in the electricity sector. Wind power generation are especially promising, as there are good wind sites in Croatia and as this technology is one of the best developed renewable energy technologies.

This paper presents analyses of different scenarios for development of Croatian energy system with integration of wind using energy storages. The current amount of wind is very small in Croatia, hence this paper focuses on solutions that could be implemented for increasing the amount of wind power in the short term. Emphasis is put on fuel efficiency for the integration technologies as the aim is to enhanced Croatia's security of supply. The storage technologies used in the analyses are pumped hydro and heat pumps.

1 METHODOLOGY

In this section, the methodology of performing such analyses is described. The section introduces the reconstruction of the Croatian Energy System an energy system analysis model as well as the assumptions and regulation strategies applied to the technical energy system analyses of the increased wind power and the storage and integration technologies.

1.1 The energy system analyses tool

Detailed energy system analysis are performed by use of the freeware model EnergyPLAN [6]. The model is an input/output model that performs annual analyses in steps of one hour. Inputs are demands and capacities of the technologies included as well as demand distributions, and fluctuating renewable energy distributions. A number of technologies can be included enabling the reconstruction of all elements of an energy system and allowing the analyses of integration technologies. The model is specialised in making scenarios with large amount of fluctuating renewable energy and analysing CHP systems with large interaction between the heat and electricity supply. EnergyPLAN was used to simulate a 100% renewable energy-system for the island of Mljet in Croatia [7] and the entire country of Denmark [5]. It was also used in various studies to investigate the large-scale integration of wind energy [8], optimal combinations of renewable energy sources [9], management of surplus electricity [10], the integration of wind power using electric vehicles (EVs)[11], the potential of fuel cells and electrolysers in future energy-systems [12]-[13], and the effect of energy storage [14], compressed-air energy storage [15]-[16] and thermal energy storage [8] [17],[18].

In the model is possible to use different regulation strategies putting emphasis on heat and power supply, import/export, and excess electricity production and using the different components included in the energy system analysed. Outputs are energy balances, resulting annual productions, fuel consumption, and import/exports.

It provides the possibility of including restrictions caused by the delivery of ancillary services to secure grid stability. Hence, it is possible to have a minimum capacity running during all hours and/or a percentage running from a certain type of plants required to secure voltage and frequency in the electricity supply.

1.2 The reference energy system

The Croatian energy system for 2007 has been reconstructed in the EnergyPLAN model. Energy consumption and supply data have been taken from [19] and [20] while hourly load data for Croatian power system have been provided by UCTE [21]. Basic data about power producing units have been obtained from Croatian utility company [22] and from [19]. Hourly production data for hydro power plants have been reconstructed from monthly values provided in [21] while hydro storage capacities have been taken from [23]. Load curve for hourly district heating demand was calculated according yearly consumption in Croatia [20] and according patterns of hourly heat demand in Denmark that are provided by EnergyPlan model.

Hourly wind power production was calculated by use of hourly wind speeds provided by program METEONORM [24] for year 1995. Croatia was divided into 8 regions (Dubrovnik, Istria, Knin, Lika, Senj, Sibenik, Split, Zadar) and for each region METEONORM provides wind speeds that are based on real measurement data or in case that measured data do not exists for exact location, METEONORM provides interpolation of wind speeds from the 3 nearest meteorological stations. To obtain hourly wind power production, hourly wind speeds are processed in H_2RES program. Firstly the average wind speed for each region is adjusted to match speeds that are stated in [26] and then, by use of power curve for 2 MW Vestas V90 wind turbine, total installed power of wind generators is increased in each region to match installed power presented by authors in [27]. Resulting curve for hourly distribution of wind power production is used in EnergyPlan calculations.

2 RESULTS OF MODELLING IN ENERGYPLAN

2.1 Comparison of reference scenarios and statistics

Reference scenarios that are calculated by EnergyPlan model are compared to statistical data for Croatia in order to see if they could represent situation in 2007 (Table 2.1.1). The biggest difference is in hydropower total primary energy supply as EnergyPlan do not multiplies energy delivered by hydropower plants. Difference in natural gas occurs as reference scenarios do not include non-energy consumption of natural gas in order to have better overview of results for energy sector. Difference in electricity production in closed system operation occurs mostly due to fact that in these calculations all electricity demand is satisfied primarily from local production units and not from the import.

Table 2.1.1. Comparison of statistics and calculations of reference scenarios.

Total primary energy supply (TWh)					
	Statistics [19], [20]	EnergyPlan Reference	Diff. from stat.	EnergyPlan Reference (closed system operation)	Diff. from stat.
Coal and coke	8.04	7.98	0.7%	8.01	0.3%
Liquid fuels	54.03	52.6	2.6%	58.28	-7.9%
Natural gas*	31.73	26.64	16.0%	29.99	5.5%
Hydro power†	11.73	4.39	62.6%	4.39	62.6%
Renewables	3.89	4.15	-6.7%	4.15	-6.7%
Electricity-import	6.36	6.36	0.0%	2.71	57.4%
TOTAL	**115.78**	**102.12**	**11.8%**	**107.53**	**7.1%**
CO_2 –emissions (Mt)					
TOTAL	**24.86**	**22.18**	**11%**	**24.39**	**1.9%**
Electricity supply (TWh)					
Hydro power plants	4.40	4.39	0.2%	4.39	0.2%
Wind power plants	0.03	0.04	-14.6%	0.04	-14.6%
Thermal power plants	5.18	5.17	0.2%	8.57	-65.4%
Public CHP plants	2.12	2.11	0.3%	2.11	0.3%
Industrial CHP plants	0.51	0.51	0.6%	0.51	0.6%
Import-Export	6.36	6.36	0.0%	2.97	53.3%
TOTAL	**18.61**	**18.58**	**0.1%**	**18.59**	**0.1%**
District heating supply (TWh)					
Public CHP plants	2.41	2.41	0.0%	2.41	0.0%
Public heating plants	0.83	0.83	0.0%	0.83	0.0%
TOTAL	**3.24**	**3.24**	**0.0%**	**3.24**	**0.0%**

2.2 The Energy Systems Analyses Methodology

The potential of introducing integration technologies into the reference energy system is analysed by varying the amount of renewable energy in the electricity system. In this study installed wind power generation is varied from 17MW to 4818 MW that corresponds to electricity generation from 0.04 TWh to 11.64 TWh. The total demand is 18.6 TWh and 2.71 TWh is covered by import (nuclear).

The technical energy system analyses are conducted for a period of one year taking into consideration demands and renewable energy production during all hours. The ability of the reference energy system to integrate fluctuating wind power is analysed with 1) the capability of the system to avoid excess electricity production and 2) the ability of the system to reduce fuel consumption and thus improve fuel efficiency. The methodology applied to these analyses is presented here:

Hour-by-hour the electricity production from wind power is prioritised as well as the production of electricity at

* non-energy consumption of natural gas not included in Energyplan reference

† Due to different accounting. Croatian energy accounting uses factor to levelize hydro power production comparable with thermal power plants.

CHP plants, industrial CHP and import (nuclear). The remaining electricity demand is met by power plants and the remaining district heating demand is met by boilers. By utilising extra capacity at the CHP plants combined with heat storages, the production at the condensing power plants is minimised and replaced by CHP production. At times when the demand is lower than the production from CHP and wind power, the critical excess electricity production (CEEP) is minimised mainly by use of either heat pumps or pumped hydro. This constitutes an open energy system in which the technologies are utilised with the aim of supplying demands in the system. The measures introduced to secure the balance between the supply from CHP and wind power and the electricity demand described may not be sufficient to reduce electricity production, and thus forced electricity export will be the result. This type of technical energy system analyses enables the investigation of the flexibility of the seven integration technologies, focussing directly on the effect on excess electricity production, i.e. regulation strategy 1) of the two types of energy system analyses.

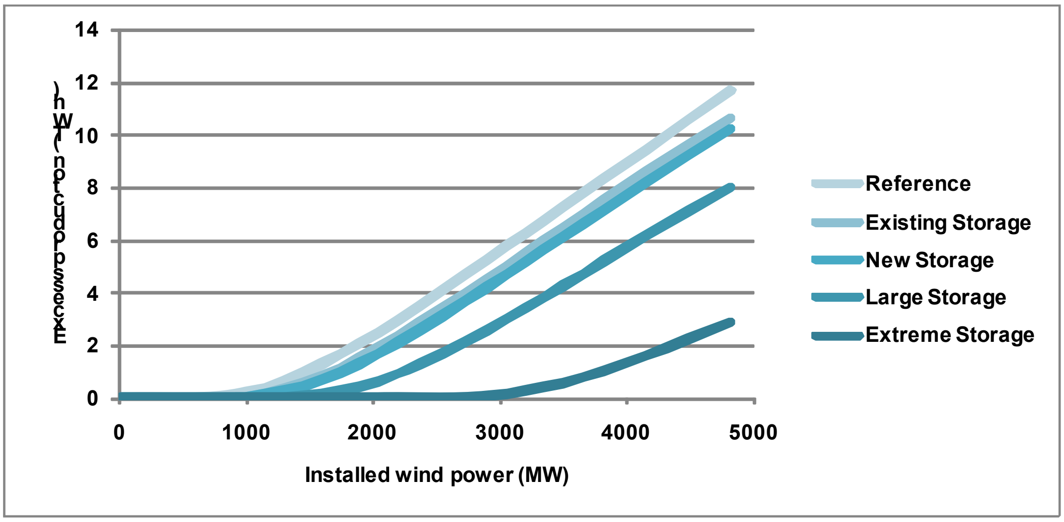

Figure 2.2.1. Installed wind power and excess electricity production in an open energy system analysis of the reference energy system without PHS and with different sizes of PHS.

The x axis in Figure 2.2.1 illustrates the installed wind power between 17 MW and 4818 MW TWh, or production equal to a variation from 0 to 62.5 per cent of the total demand (18.61 TWh) or 0 to 100 per cent of the demand that is not covered by nuclear import or domestic hydropower production. The y axis illustrates the excess electricity production in TWh. The less ascending curve illustrates a better integration of RES.

The second of the two types of energy system analyses, i.e. regulation strategy 3), builds on the first analyses. However, here any excess electricity production is converted or avoided; first, by replacing CHP production by boilers in the district heating systems and, secondly, by stopping wind turbines. The import/export is of course zero, as it is a closed system. All excess electricity production is converted or avoided and the entire primary energy supply (PES) excl. the RES (wind power) of the system is presented.

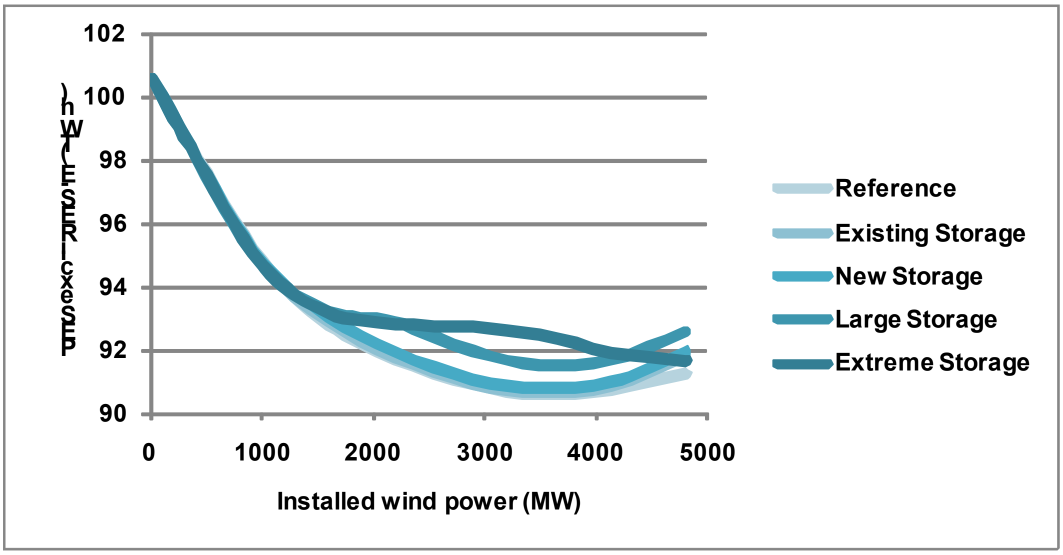

Figure 2.2.2. Primary energy supply (PES) in a closed energy system analysis of the reference energy system with and without PHS and CHP regulation.

The result of such analyses represents a *closed* energy system. The x axis shows the installed wind and the y axis illustrates the PES excl. the RES of the entire energy system. The less PES excl. the RES, the more flexible and fuel-efficient is the energy system. Again, a total of nine energy system analyses have been conducted hour-by-hour for a year for both types of CHP regulation. The advantage of presenting PES excl. the RES instead of PES incl. the RES is the fact that such results can reveal the ability of a technology to utilise RES, such as wind power, to efficiently replace other fuels.

The analyses are conducted with the following restrictions in order to secure the delivery of ancillary services and achieve grid stability (voltage and frequency). At least 40 per cent of the power or as a minimum 490 MW (at any hour) must come from power production units capable of supplying ancillary services, such as central PP and CHP. The distributed generation from RES and small CHP units is not capable of supplying ancillary services in order to achieve grid stability. In the analyses here, the Croatian energy system is treated as a one point system, i.e. no internal bottlenecks are assumed.

It is not the aim to recommend the precise optimal solutions for integration of RES in this paper. However, it is the aim to provide information on which technologies are fuel efficient and able to integrate RES and which approximate sizes are relevant.

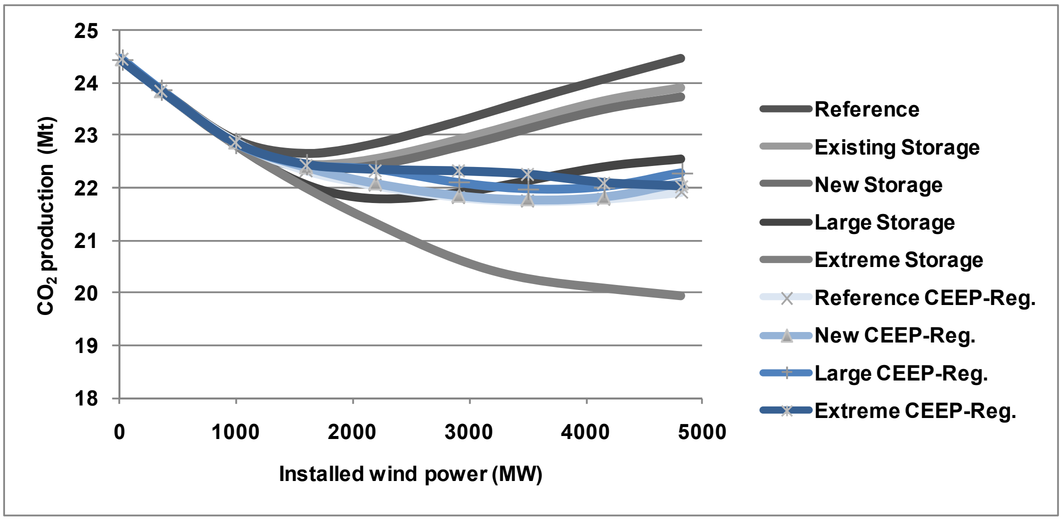

Figure 2.2.3. CO_2 emissions in the reference energy system with and without PHS and CHP regulation.

Possibilities for reduction of CO_2 emission from energy sector is presented on Figure 2.2.3. Diagram also shows that for different sizes of PHS there is optimum of installed wind due the fact that there is certain amount of stabilization load that needs to be satisfied from conventional units.

2.3 Wind Power Generation Distribution Curves

Using the reference energy system for 2007 the amount of wind power is increased. Such analyses require considerations about the future distribution of the production from wind power in Croatia. The results of analysis will be more accurate if hourly wind production data will be available or at least hourly wind speeds that are measured on the sites where wind power plants will be constructed. In 2007, in Croatia there were only 2 wind farms with installed power of 17 MW which is not enough for good representation of wind power production for whole country, for example in 2007 Denmark had approximately 3000 MW with long history of collecting data which enables good input for Energy Plan calculations. Constructed data for wind power production in Croatia in comparison with Danish are presented in Figure 2.3.1.

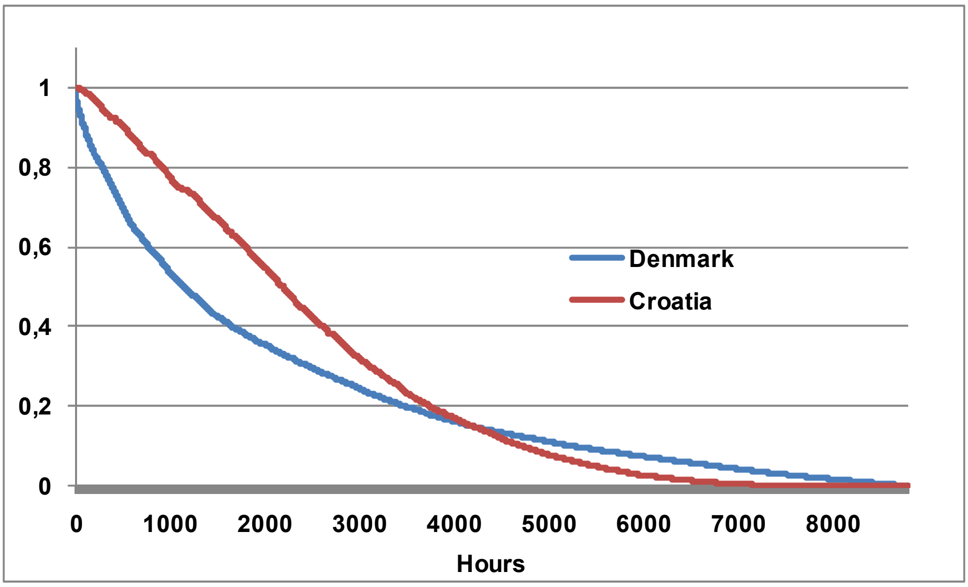

Figure 2.3.1 Comparison of constructed wind power production data for Croatia with real wind production in Denmark (EnergyPlan wind distribution data).

2.4 Integration Technologies Analysed

In this section the technologies, capacities and efficiencies of the integration technologies analysed are presented.

In reference scenario existing pumped hydro storage in the system is removed in order to have better overview of results. Installed power of pumps and turbines, capacities of storages and efficiencies of technologies are given in Table 2.4.1.

Table 2.4.1. Technology data in PHS scenarios.

Scenarios / Technology	Reference	Existing Storage	New Storage	Large Storage	Extreme Storage
Turbines (MW)	0.00	281.74	375.19	936.19	3196.00
Pumps (MW)	0.00	246.00	344.90	1018.90	3169.00
Storages (GWh)	0.00	24.14	40.86	274.00	450.00
Turbines eff.	0.00	0.83	0.83	0.85	0.85
Pumps eff.	0.00	0.78	0.78	0.83	0.83

In the group of calculations without pumped hydro storages, large scale-heat pumps and heat storages in district heat areas are used in order to increase wind power penetration and decrease CEEP. Heat storage capacity in all scenarios is set to 20000 MWh, tested sizes of heat pumps are 25 MWe, 75 MWe and 150 MWe and COP (coefficient of performance) is set to 3.

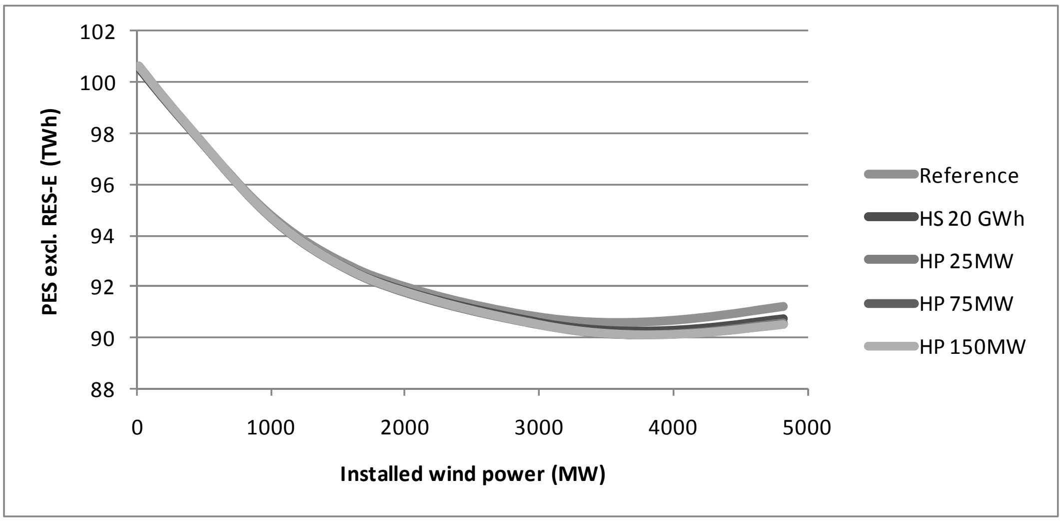

Figure 2.4.1. Primary energy supply (PES) in a closed energy system analysis of the reference energy system with and without heat storages, heat pumps and CHP regulation.

Finally, one calculation is made integrating both pumped hydro technologies with heat storages and large heat pumps. Sizes of PHS are the same as in New Storage scenario with 150 MWe in heat pumps and heat storage of 20 GWh. Used Regulation strategy is 3 with balancing heat and electricity demand with reduction of CHP and shutting down PP and RES units. Results for integrating scenario are presented in Table 2.4.2.

Table 2.4.2. Results of calculation in integrating scenario.

Installed Wind (MW)	CEEP (TWh)	PES without RES (TWh)	RES (TWh)	CO_2 Mt
17	0.00	100.61	4.44	24.46
360	0.00	98.41	5.27	23.85
1000	0.08	94.81	6.80	22.89
1600	0.36	92.99	7.96	22.42
2200	0.53	91.79	8.70	22.12
2900	0.65	90.87	9.26	21.89
3500	0.75	90.40	9.56	21.77
4150	0.92	90.42	9.72	21.78
4818	1.43	91.34	9.83	22.03

CONCLUSION

Paper presents new approach in planning of Croatian energy system with significant emphasis on integration of wind energy by use of different energy storage technologies and system regulation strategies. It shows that 10% of total electricity demand could be covered by wind energy without any significant change in current system and without exporting of electricity excess to neighbouring countries. With specific regulation of wind power plants, current large conventional power plants and CHP penetration could be doubled or at 20%. But this will lead to significant rejection of RES potential, around 30% and to utilize this excess, large pumped hydro storages should be build.

The better results for penetration could be achieved by decreasing stabilization load that is provided by conventional units or by replacing it with large hydro power stations. This option was not included in presented calculations so it will be worth of investigation. Moreover, use of existing CHP and installations of heat storages should be further investigated if the current district heating systems become based on lower temperature operation. Reason that the storage and heat pumps have so little effect (Figure 2.4.1) is, that the district heating demand is small compared to the installed PP (of which the 500 MW CHP is part) and the electricity demand. Hence the results with storage does not change so much, because the alternative CHP could operate as condensing units.

Results of this study should be taken with certain reserve until constructed data for wind speeds and wind power production are verified by other calculations/measurements or until they are compared to similar results for other countries (Denmark, Irland etc.). The calculated load factor for wind power plants in Croatia is at 27% which is to high as experts expect it to be somewhere between 20%-25%. Another big issue is stabilization load which certainly could be provided by large hydropower so it should be somehow included in calculations as EnergyPlan has few options to regulate that issue. It also shows importance that new power plants that will be built in Croatia in next 10 years should be made with bigger flexibility in operation. Moreover as there are 4818 MW of wind power applications in current Croatian registry for wind power plants. Extreme pumped hydro energy storage might not be feasible do to economically and environmentally concerns but it could provide long term solution for 100% RES system and should be compared to investment into nuclear power plant.

Presented scenarios are just part of research which investigates planning and development of Croatian energy system and it will cover other locally RES that are present in Croatia (solar, geothermal, biomass, small hydro) and will include other energy consuming sectors (industry, transport, buildings). Further work will also include economic analysis, market optimization, analysis of environmental and social aspects of proposed development scenarios and improvement of reference energy system.

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